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Research Article

Anthropogenic disturbance produces divergent effects in the community structure and composition of tropical semi-evergreen forests in the Eastern Himalaya

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Abstract

Studies documenting anthropogenic disturbance-driven changes in forest communities of the Eastern Himalaya, a global biodiversity hot spot, are largely lacking. We studied six forest sites of tropical semi-evergreen forests in Arunachal Pradesh in the Eastern Himalaya to understand the effects of varying disturbance intensities on the forest community structure and composition. Based on the magnitude of disturbance, forest sites were classified as experiencing low, moderate and high disturbance. Mean species richness (SR) of trees and shrubs decreased from low disturbance to high disturbance. Mean SR of herbs was maximum in moderately disturbed forest sites. Maximum values of the Shannon-Wiener Diversity Index (SD) were recorded for trees at sites with low disturbance, for shrubs at sites with high disturbance and for herbs in moderately disturbed forests. Pilelou Evenness Index (EI) values were maximum for trees at sites with high disturbance, while maximum EI values for shrubs and herbs were recorded in the forest sites with low disturbance. The number of tree families decreased from 18 to 13 in the forests with low and high disturbance, respectively. Moderate disturbance led to increased herb species richness and diversity, while increasing disturbance produced contrasting effects on trees. High anthropogenic disturbance led to low species richness, but high diversity amongst shrubs. Our investigations suggest that the magnitude of disturbance elicits differential responses in different physiognomic classes in the forest ecosystems and further our understanding of the effects of disturbance in tropical forest ecosystems of a global biodiversity hotspot.

Key words: biodiversity, hotspot, species diversity, species richness

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Introduction

Tropical forests form a major component of the global biodiversity hotspots, as well as the world's most endangered ecosystems (Myers et al. 2000; Mittermeier et al. 2011). As such, global biodiversity to a great degree is threatened due to the rapid degradation of tropical forests (Laurance et al. 2012). Equally well recognised is the fact that, world-over, tropical forests with the least anthropogenic impacts are potential centres of undescribed species diversity due to their greater structural complexity and richness compared with any other biome

(Giam et al. 2012). Notwithstanding their conservational significance, tropical forests face high levels of threat to their biodiversity and ecosystem services due to deforestation, agricultural expansion, urbanisation and widespread developmental projects such as dams (Wright 2005; Pandit et al. 2007, 2014, 2023). A comprehensive global assessment of the impact of disturbance on biodiversity showed that primary forests are irreplaceable in preserving tropical biodiversity (Gibson et al. 2011). When disturbed, tropical forests take a long time to recover; an average recovery time of 503 years was reported in a global assessment of tropical forests affected by disturbance (Cole et al. 2014).

The effects of disturbance on the structure and dynamics of vegetation communities have been contentious in ecological literature. Some regard disturbance as a negative influence as it destroys the climax assemblages (Clements 1936), while others regard it as a positive stimulus because it removes the dominant species and results in an increase in species diversity (Huston 1979). The proponents of the intermediate disturbance hypothesis suggest that species diversity is likely to be the highest at intermediate levels of disturbance intensity or frequency (Connell 1978; Miller et al. 2011). Yet others argue that disturbance not only reduces diversity, but also disrupts natural ecosystem services with significant effects on a forest ecosystem's vegetation, soil, water resources, wildlife and microclimate (Tilman and Lehman 2001; Pandit and Grumbine 2012; Pandit et al. 2014), even though various studies have highlighted the role of disturbance as a major factor in determining population and community structure. The causes, rates, size, pattern and trends of landscape changes in the Tropics are not extensively documented at the local and regional levels.

Arunachal Pradesh, the easternmost state of India, comprising the major part of the Eastern Himalaya global biodiversity hotspot, is regarded as one of the most sensitive areas with a high risk of deforestation (Roy and Joshi 2002; Pandit et al. 2007). The total forested area of Arunachal Pradesh is about 67,680 km^2, of which nearly 80% (53,850 km^2) exists as dense forests (Pandit et al. 2007). Of nearly 6000 species of flowering plants reported from the Arunachal Himalaya, 30–40% have been reported to be endemic to the region (Behera et al. 2002). However, in recent years, deforestation and anthropogenic pressures on land due to diverse economic interests, such as infrastructure and hydro-power development, have emerged as major drivers of land-use change and forest loss in the Eastern Himalaya (Pandit 2017). Notably, this region is poised to lose nearly one-fourth of the endemic species across various taxonomic groups by the turn of this century due to ongoing deforestation (Pandit et al. 2007) with additional species losses projected due to unprecedented dam building activities and climate change (Grumbine and Pandit 2013; Telwala et al. 2013).

Earlier studies on the effect of disturbance on the vegetation communities in the Arunachal Himalaya have been limited to the effect of disturbance only on the tree layer (Bhuyan et al. 2003), the regenerative ability and patterns of important tree species (Duchok et al. 2005) and the population structure of tree species in various forest stands (Nath et al. 2005). Little attention has been paid to understanding the effects of disturbance on the overall community structure and dynamics of these forests. This study aims to fill this gap by focusing on the effects of disturbances on all the physiognomic classes in these forests, viz. trees, shrubs and herbs. In this study, we identified and examined the effects of anthropogenic disturbances on the tropical forest stands of Arunachal

Pradesh, Eastern Himalaya in relation to their species diversity, community composition and structure. We also carried out a comparative analysis of varying disturbance intensities on different community characteristics in these tropical forests. Given the concentrated developmental activities unfolding in the region over the last decade, this empirical analysis is timely for documenting the impact of anthropogenic disturbances on the rich tropical forests of the Eastern Himalaya. The findings of this study are relevant considering the high conservation value of this global biodiversity epicentre and a general lack of community ecology studies on the tropical forest ecosystems in the Eastern Himalaya.

Materials and methods

Study area

We studied six forest sites located in Aalo Forest Division, West Siang District of Arunachal Pradesh (Fig. 1). The study area is located between 28°2°'50"N–28°40'21"N latitude and 94°21'42"E–94°42'32"E longitude with elevations ranging from 450 m to 950 m. The major forest type of the study area is tropical semi-evergreen forest, which corresponds to 2B/1S1 Sub-Himalayan light alluvial semi-evergreen forest (Champion and Seth 1968). The

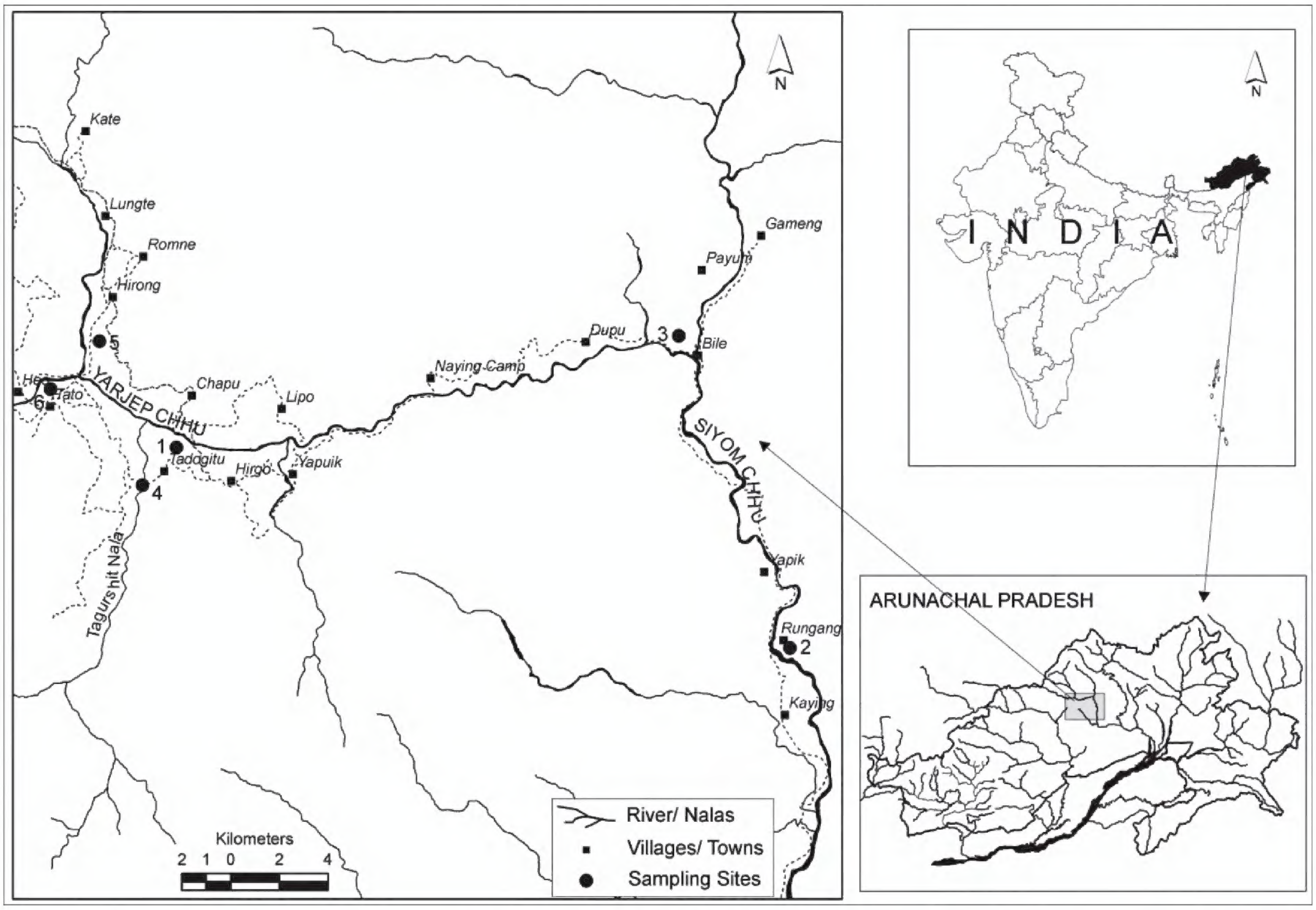

Figure 1. Map of the study area showing the locations of six sampling sites (1-Tatogito, 2-Roying, 3-Poma Basti, 4-Tagurshit, 5-BB Camp Bamboo bridge area, 6-BB Camp Basti area). Each sampling site represents a different forest site. Sampling was undertaken to assess the structure and composition of the vegetation community at each site during pre-monsoon (March-April), monsoon (July) and post-monsoon (October) seasons.

area is characterised by high monsoon rainfall with an annual average of 2300 mm, moderate temperatures ranging from 18°–22°C and high relative humidity levels between 77% and 98%. These forests, therefore, come structurally closest to the tropical rainforests of the Malayan Archipelago in Southeast Asia dominating the region east of the Bay of Bengal.

Sampling

Sampling in six forest sites was undertaken to assess the structure and composition of the vegetation community of the study area. Sampling locations were randomly chosen in each forest site in such a manner that the maximum possible representative vegetation of the respective forest site was covered. In each forest site, three physiognomic classes, i.e. trees, shrubs and herbs were surveyed, sampled and analysed using the standard nested quadrat sampling method. Each nested quadrat design contained subplots of 10 m × 10 m [for recording tree species with circumference at breast height (cbh) > 30 cm], 5 m × 5 m (for recording shrubs and saplings with 10–30 cm cbh), and 1 m × 1 m (for recording herbs with < 10 cm cbh) (Manish et al. 2017). In the context of the present study, we defined saplings as the individuals of tree species that are generally low in height (up to 5 m in height and having cbh of 10–30 cm). The nested quadrats were laid over a 1 km long line transect along the hill slope. Standard species-area curves were used to determine the number of quadrats required to cover maximum species diversity at each sampling location. To account for seasonal community fluctuations, sampling was carried out in the pre-monsoon (March-April), monsoon (July) and post-monsoon (October) seasons for three years. The data on the vegetation composition was quantitatively analysed for species richness (SR) and other phytosociological characteristics including density, abundance, frequency, dominance, importance value index (IVI), Shanon-Wiener Diversity Index (SD) and Evenness Index (EI).

Disturbance gradient

Following the methods of Sagar et al. (2003) and Sapkota et al. (2010) with minor modifications, six sampling sites were ranked according to the intensity of anthropogenic disturbance they experienced. Four different sources of disturbance were recognised, viz. road, human habitation, tree-felling/lopping and herbivory (grazing by domestic cattle) (see Table 1). The relative impact of each disturbance source was estimated as follows:

a) Road: A sampling site furthest from the road head was assumed to experience minimum disturbance and designated as having an impact equal to 1. The impact for other sites was calculated as ratios of the distance of respective sites from the road to the distance of the site with an impact of 1 (Sagar et al. 2003).
b) Human habitation: The sampling site located furthest from a village/human settlement was taken to experience an impact of 1. The ratio of the distance of other sites from their respective village/human settlements to the distance of the site with an impact of 1 was taken as the impact for other sites (Sagar et al. 2003).

c) Logging/lopping: Relative density and relative basal area of the damaged individuals were used as a measure to rank logging/lopping as impacting a site (Sagar et al. 2003; Sapkota et al. 2010). The relative density of damaged individuals was calculated as the ratio of the sum of the density of damaged individuals and the total density of individuals (damaged + standing). Likewise, the relative basal area of damaged individuals was calculated as the ratio of the sum of the total basal area of damaged individuals and the total basal area of all individuals (damaged + standing). Sampling sites with the lowest values of relative density and relative basal area of damaged individuals were assigned to experience an impact of 1. The impact on other sampling sites was determined as the ratio of the total relative basal area and relative density of a particular site to the total relative basal area and relative density of damaged individuals at the site with an impact of 1, respectively.
d) Browsing/grazing: Relative density of damaged saplings (tree individuals less than 5 m high and with 10–30 cm cbh) was calculated to estimate the impact due to herbivory (browsing/grazing) by domestic cattle. The relative density of saplings was calculated as the ratio of the sum of the density of damaged saplings to the total density of all saplings (damaged + undamaged). The sampling site with the lowest value of relative density was assigned an impact of 1. The impact on other sampling sites was determined as the ratio of the relative density of damaged saplings at a particular site to the relative density of saplings at a site with an impact of 1, respectively.

After the relative impact of each of the four disturbance sources was estimated, their individual scores were summed to yield a cumulative impact at each of the six sampling sites. This cumulative total impact was taken as a surrogate for the degree of disturbance at each site. Based on the disturbance intensity, we classified different forest sites under the following three anthropogenic disturbance classes: (i) Least disturbed forest site with a total impact of less than 10, (ii) Moderately-disturbed forest site having a total impact of less than 100 and (iii) Highly-disturbed forest site having a total impact of greater than 100. Though there may be other sources of anthropogenic disturbance in the study area like herb collection, firewood cutting and intentional fire, we focused on the relative impacts of only road construction, human habitation, logging/lopping and browsing/grazing as these were the only predominant sources of disturbance as per our field study. There are no records of any rare, endangered or threatened medicinal plant species in the study area.

Table 1. Relative impacts for each disturbance source in six tropical semi-evergreen forest sites in Arunachal Pradesh.

Disturbance source		Relative impact at forest sites					
		Tatogito	Roying	Poma Basti	Tagurshit	BB Camp Bamboo bridge area	BBCamp Basti area
Road		1	20	25	40	50	100
Habitation		1	4	8	1.3	80	100
Tree cutting/ lopping	Relative density	1	1.83	4	2.67	5.17	6.17
	Relative basal area	1	5	8	12	14	12
Browsing/Grazing		1	1.93	3.67	3.97	4.65	4.78
Total impact		**5**	**32.76**	**48.67**	**59.97**	**153.82**	**222.95**

Data analysis

Each of the six sites was surveyed for angiosperm taxa. The collected species were assigned to their respective plant families and the three physiognomic classes (trees, shrubs and herbs). Each site was analysed for density, abundance, frequency and dominance of constituent flora using standard procedures of vegetation sampling (Curtis and McIntosh 1950). The Importance Value Index (IVI) for each plant species was determined as the sum of relative density, relative frequency and relative dominance (Curtis and McIntosh 1950). For determining dominance, total basal area (TBA) for tree species and cover for shrub and herb layers were calculated. TBA was measured using the formula: TBA = mean basal area × density, where, mean basal area = (average circumference at breast height) $^2/4\pi$. The cover value for shrub and herb layers was measured by the formula: Cover = mean cover × density, where, mean cover = π × (average diameter of species)^2 × 0.25.

In order to characterise the community structure of the investigated sites, the following variables were analysed: (i) SR - determined as the total number of species per sampling unit (Whittaker 1975), (ii) SD - calculated following Shannon and Weiner (1963) and (iii) EI - calculated following Pielou (1969). A plant family with the largest number of species was considered the most dominant one in a site. The population structure of the studied sites was examined using the density-diameter distribution of the trees (Rao et al. 1990). Following standard literature, the trees were distributed into six girth classes with successive increments of 30 cm, i.e. 30.1–60 cm, 60.1–90 cm, 90.1–120 cm, 120.1–150 cm, 150.1–180 cm and 180.1–210 cm (Majumdar et al. 2012). Unstacked one-way analysis of variance (ANOVA) was used to test the significance of differences in mean SR and mean density for different physiognomic classes across the sampling sites. We used Minitab 16 (Minitab Inc., State College, PA, USA) software for this analysis. The total basal area of tree species was used for ordination analysis of different sites using Principal Component Analysis (PCA) to investigate if varying disturbance magnitudes exerted significant influence on tree species distribution (Sagar et al. 2003). Before PCA analysis, the values of the total basal area were log (x+1) transformed to control for skewness in the dataset. PAST version 2.13 software was used for PCA analysis.

Results

The study sites varied in nature and intensity of disturbance they experienced and a noticeable disturbance gradient between them was discerned (Table 1). Tatogito forest site was the least disturbed; Roying, Poma Basti and Tagurshit were moderately disturbed, while BB Camp Bamboo Bridge area and BB Camp Basti area were highly-disturbed forest sites (Table 1).

A total of 160 species were recorded at these sites of which 54 were trees, 30 shrubs and 76 herbs (Table 2). The emergent tree layer in almost all the forest sites mainly comprised *Macaranga denticulata* (Blume) Müll.Arg., *Alnus nepalensis* D.Don and *Sauraria punduana* Wall. The shrub layer was represented by *Melocalamus compactiflorus* (Kurz) Benth., *Boehmeria penduliflora* Wedd. ex D.G.Long, *Pinanga gracilis* Blume, *Oxyspora paniculata* (D.Don) DC. and *Alsophila spinulosa* (Wall. ex Hook.) R.M.Tryon, while the herbaceous layer mainly

Table 2. Shanon-Wiener Diversity Index and Pilelou Evenness Index for different vegetation layers in six forest sites along a disturbance gradient.

Vegetation parameters		Forest sites					
		Tatogito	Roying	Poma Basti	Tagurshit	BB Camp Bamboo bridge area	BB Camp Basti area
Shanon-Wiener Diversity Index	Trees	2.79	2.61	2.54	2.42	2.47	1.65
	Shrubs	1.75	1.51	1.34	1.62	2.04	1.73
	Herbs	1.9	2.17	2.55	2.96	2.42	2.03
Pilelou Evenness Index	Trees	0.13	0.15	0.16	0.17	0.18	0.24
	Shrubs	0.25	0.17	0.22	0.23	0.2	0.16
	Herbs	0.19	0.15	0.17	0.09	0.15	0.14

comprised *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda, *Musa balbisiana* Colla and *Pilea scripta* (Buch.-Ham. ex D.Don) Wedd. Mean SR varied significantly for trees, shrubs and herbs between different sites (Fig. 2A). Mean SR for trees and shrubs decreased from the least disturbed (SR = 3.2 ± 1.03, SR = 2 ± 0.82) to highly disturbed (SR = 1.9 ± 0.57, SR = 1.5 ± 0.53) sites. However, for herbs, mean SR was the highest in moderately disturbed site (SR = 3.7 ± 1.2) (Fig. 2A). Maximum SD for trees was recorded at the least disturbed sites, while the highest SD for shrubs was recorded at the highly-disturbed sites. Herbs, on the other hand, showed maximum values of SD at the moderately-disturbed forest sites (Table 2). The maximum value of EI for trees was recorded in the highly-disturbed forests in contrast to shrubs and herbs in which maximum values were recorded at the least disturbed forest sites (Table 2). Similar to SR, mean density of species also showed significant variation for trees, shrubs and herbs between different sites (Fig. 2B). Maximum mean tree density (MTD) was recorded in the least disturbed forest (MTD = 3.4 ha^{-1} ± 0.5) and minimum values were recorded at the highly-disturbed sites (MTD = 2.55 ha^{-1} ± 1.2) (Fig. 2B). Maximum mean shrub density (MSD) was recorded at the highly-disturbed forest site (8.40 ha^{-1} ± 1.7) and minimum at the least disturbed forest site (6.30 ha^{-1} ± 0.8) (Fig. 2B). Maximum mean herb density (MHD) was also recorded at the highly disturbed site (23.3 ha^{-1} ± 2.7) and minimum in the least disturbed site (6.70 ha^{-1} ± 1.1) (Fig. 2B). Overall, the density-diameter distribution pattern showed a gradual decrease in the density of trees with an increase in diameter class (Fig. 3). Across the investigated sites, maximum number of trees belonged to the lower diameter classes (30.1–90 cm cbh) and minimum numbers were in the higher diameter classes (150.1–210 cm cbh). All six forest sites also showed significant variation in terms of the total basal area of tree species. The PCA ordination plot using the total basal area of tree species showed a clear separation of the six sites (Fig. 4).

Species composition showed varied dominance of different species at different forest sites. Species listed in Suppl. material 1: appendix A (10 trees, 17 shrubs and 12 herbs out of total 160 species) dominated the forest vegetation across sites with relatively higher IVI and TBA/cover. *Alnus nepalensis* D.Don, *Engelhardtia spicata* Lechen ex Blume and *Albizia odoratissima* (L.f.) Benth. emerged as the most dominant tree species in the least, moderately- and highly-disturbed forest sites, respectively. Amongst shrubs, *Boehmeria penduliflora* Wedd. ex D.G.Long was the most dominant in the least disturbed site. *Bambusa tulda* Roxb. and *Polygonum molle* D.Don were the most dominant shrub species

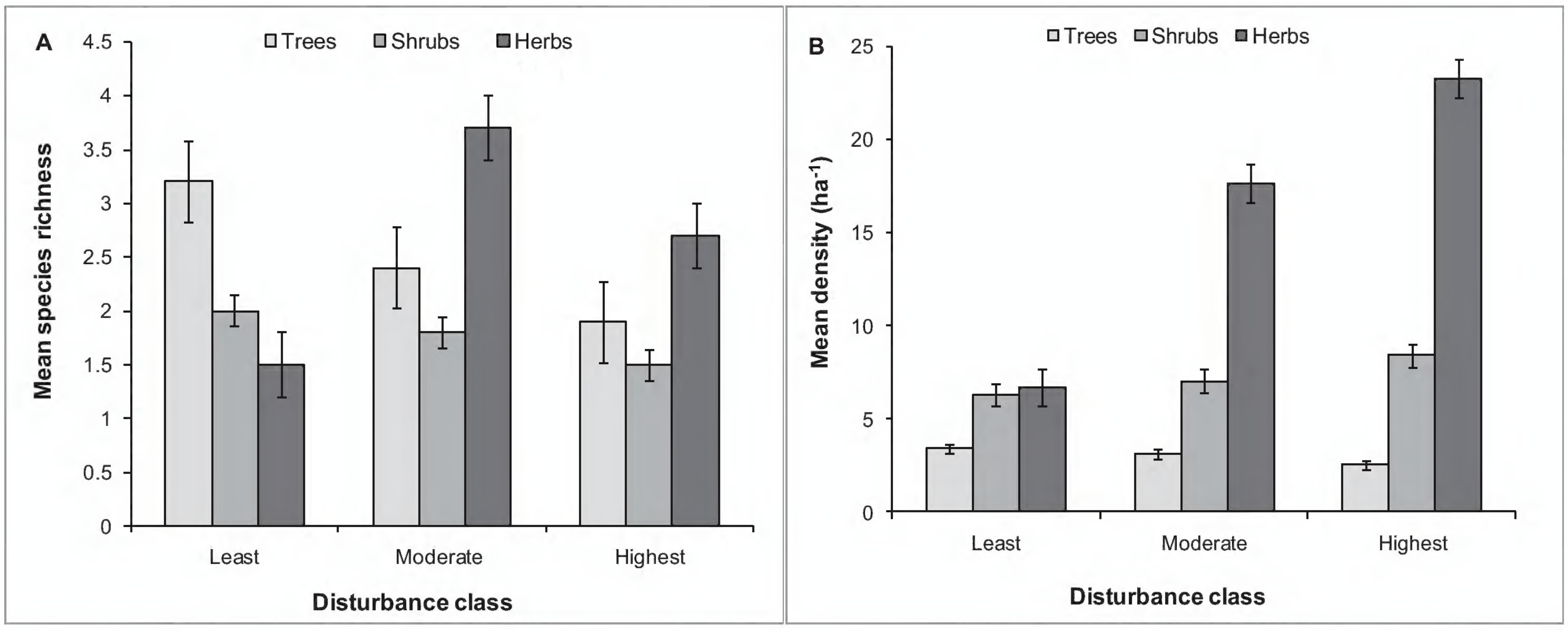

Figure 2. Effect of anthropogenic disturbance on vegetational parameters of different forest sites. (A) Variation of mean species richness with disturbance classes for trees, shrubs and herbs, (B) Mean density as related to disturbance classes for different vegetation layers. Error bars represent the standard deviation.

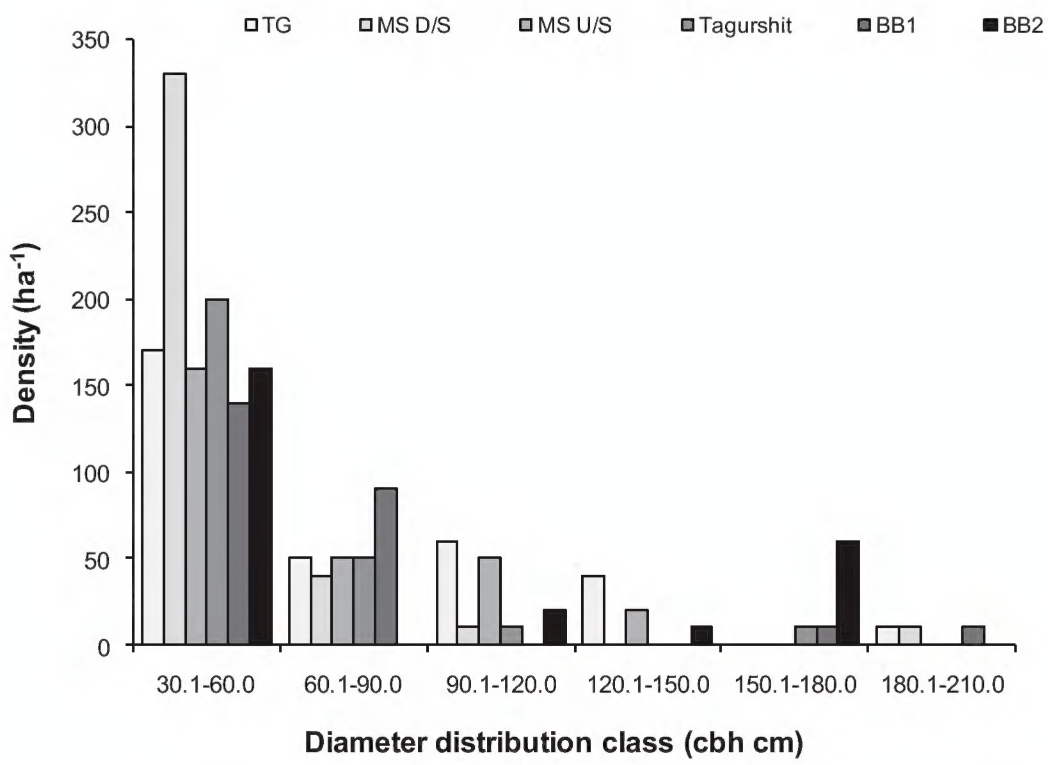

Figure 3. Density-diameter distribution of trees in different forest sites (TG - Tatogito, RO - Roying, PB – Poma Basti, TAG - Tagurshit, BB1 - BB Camp Bamboo bridge area, BB2 - BB Camp Basti area). In all the forest sites, most trees had maximum density in the lower diameter classes (30.1–90 cm cbh) and minimum density in the higher diameter classes (150.1–210 cm cbh).

in the moderately- and highly-disturbed sites, respectively. In herb strata, *Hellenia speciosa* (J.Koenig) S.R.Dutta, *Alpinia nigra* (Gaertn.) B.L.Burtt and *Ageratum conyzoides* L. were the most dominant species in the least, moderately- and highly-disturbed sites, respectively (Suppl. material 1: appendix A). The number of tree families decreased from 18 at the least disturbed site to 13 at the highly-disturbed site (Suppl. material 1: appendix B). Betulaceae and Araliaceae were the most dominant families and Moraceae was a co-dominant family in the least disturbed forest sites. Euphorbiaceae was the most dominant family and Anacardiaceae a co-dominant at the moderately-disturbed site. In

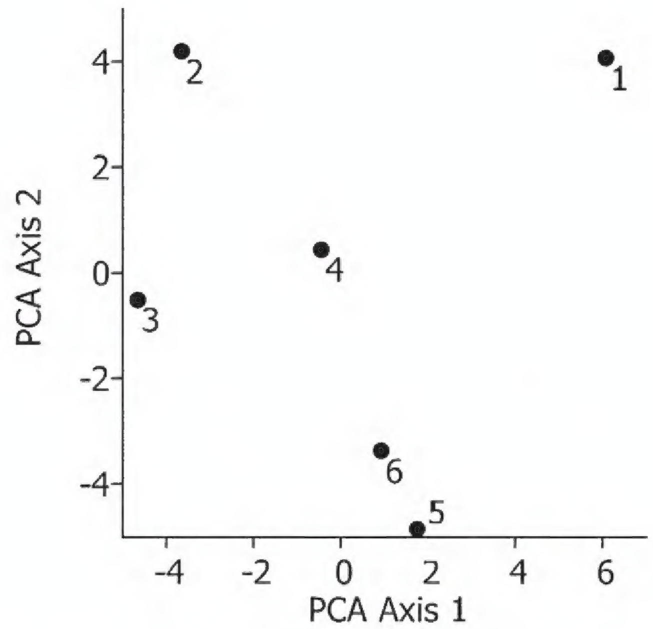

Figure 4. Principal Component Analysis (PCA) ordination plot, based on total basal area of tree species in six forest sites (1 - Tatogito, 2 - Roying, 3 - Poma Basti, 4 - Tagurshit, 5 - BB Camp Bamboo bridge area, 6 - BB Camp Basti area). A total of 51.92% variation in species composition was explained by the first two principal components (PCA axis 1 – 27.14%, PCA axis 2 – 24.78%) in the ordination plot.

the highly-disturbed forest sites, Araliaceae and Moraceae were recorded to be the most dominant families, while Betulaceae, Bignoniaceae, Anacardiaceae and Mimosaceae were the co-dominants. Amongst the recorded families, only Anacardiaceae was present in all the forest sites (Suppl. material 1: appendix B).

Discussion

Anthropogenic activities are a looming threat to the biodiversity of the Himalayan forests and have been responsible for the significant transformation of its landscape (Pandit et al. 2014). Earlier studies have shown that anthropogenic pressures on the forests of Arunachal Pradesh and adjoining hill regions of northeast India have historically been in the form of logging for traditional agriculture like *Jhum* (slash and burn) and selective felling by the Forest Department (Singh et al. 2003). The cycle of shifting cultivation in the region is 6 to 7 years. The growing human population and the increasing number of domestic cattle and livestock have necessitated more harvest of timber, fuel wood and uncontrolled grazing (Pandit 2017).

All six study sites in the present paper are directly affected due to various human activities including ongoing hydroelectric power projects in the study area. We were able to locate a total of 105 households in the study area. Scheduled tribe population accounts for more than 95% of the total population (CISMHE 2010). These villages are very poor in literacy that is attributed to low education facilities. Average literacy is 45%, being relatively high in the male population. Farming remains the main occupation of the people. The local farmers continue to practise the age-old slash-and-burn (*Jhum*) method of cultivation. The main crops grown in the region are paddy, millets and chillies. Nearly 44% of the total population constitutes the total workforce employed in agriculture (CISMHE 2010). A good number of households of Tato and Roying are employed in small-scale businesses. The level of utilisation of medicinal plants in the region is quite low. The local population use *Cautleya gracilis* (Sm.) Dandy, *Hellenia*

speciosa (J.Koenig) S.R.Dutta, *Urtica dioica* L., *Alpinia nigra* (Gaertn.) B.L.Burtt, *Piper pedicellatum* C.DC. etc., but as highlighted earlier, there are no reports of any rare, endangered or threatened medicinal plant species in the region.

We recorded significant changes in the community composition of the investigated forests with increasing disturbance levels. Moderate disturbance led to increased herb richness and diversity, while high disturbance levels had the opposite effect on trees. Shrubs showed low richness, but high diversity with increasing disturbance. These results confirm earlier findings of Bhuyan et al. (2003) in a tropical wet evergreen forest in Arunachal Pradesh and Mishra et al. (2004) in the adjoining Meghalaya forests, who reported decreased tree species diversity, density and basal area along the disturbance gradient. Our results suggest that disturbance of varying magnitudes produces differential responses by different physiognomic classes in the forest ecosystems. Higher tree species richness and diversity were observed in forests with the least disturbance. It is well known that the stability and resilience of an ecosystem depend on the magnitude of species diversity and the number of interactions between them (MacArthur 1955; Leigh 1965). Evidence, based on theoretical and empirical studies, shows that a decrease in species diversity hastens the simplification of ecological communities causing negative impacts on the ecosystem services (McCann 2000).

We observed that, with increasing disturbance, tree species richness decreased, while their Evenness increased. For shrubs and herbs, maximum values of the Evenness Index were found in forests with the least disturbance. The negative relationship between richness and Evenness has also been reported elsewhere (Symonds and Johnson 2008). Uniyal et al. (2010) also showed that the Evenness Index for tree species was highest in the most disturbed forests. In a major modelling exercise, Svensson et al. (2012) showed that Evenness increased with increasing disturbance for all levels of productivity. These findings including the present investigations suggest a negative relationship between richness and Evenness. The inverse relationship between species richness and Evenness mediated by disturbance alludes to the fact that, with increasing disturbance, abundance of dominant species is reduced. The tree basal area decreased with increasing disturbance levels and a clear gradation between disturbance and basal area was reflected by the separation of the forest sites in the PCA ordination analysis. In earlier studies, decreasing tree basal area has been directly related to the disturbance index and deteriorating forest stand productivity (Smiet 1992). The density-diameter distribution curves in the present study depicted a successive reduction in the number of trees of higher girth classes and disturbance increased thereby preventing these ecosystems from attaining a climax stage and perpetuation of seral stages. Maximum tree density in the lower diameter classes (30.1–90 cm cbh) across the forest sites suggests selective removal of individuals of higher diameter which is clear from the data on logging.

Our results suggest that disturbance impacts tree species more and arrests climax community formation by the proliferation of disturbance-tolerating shrub and exotic herbaceous species. *Ageratum conyzoides* L., an exotic invasive herb, was absent in the forests with low disturbance, but dominated the sites experiencing high disturbance. Numerous earlier studies have reported the invasion of disturbed sites by exotic invasives (Lodge 1993; Martin et al. 2009). The reasons for the proliferation of invasives in disturbed sites include reduced com-

petition from native species (Davis and Pelsor 2001), low suppression of exotic species by lack of closed cover of native species (Manish 2021), faster growth rates than native species (Burke and Grime 1996) and higher local nutrient resource levels (Levine et al. 2003). Logging creates forest gaps which becomes a critical factor for invasion. In less disturbed forest fragments, denser canopy cover leads to the presence of low light levels in the understorey. Since exotic species generally tend to be light-demanding (Fine 2002) and shade intolerant (Mack 1996), exotics are absent from undisturbed habitats and are more likely to be found in only disturbed environments where light availability is greater.

Conclusion

All five sites, except the one with the least disturbance, experienced varying intensities of biotic pressure in the form of lopping for timber and firewood and grazing by domestic animals. Loss of plant diversity and changes in community structure in terms of composition, species density and population structure have resulted from these anthropogenic disturbances in the tropical semi-evergreen forests of Arunachal Pradesh. The help of local communities can be sought in the conservation of the forests through participatory activities by the grant of title rights, delineating specific areas for browsing/grazing, fixing permits for extraction of timber wood etc. The policy-makers can do well to involve the local communities in conservation programmes and sensitise them about the ill effects of anthropogenic disturbances rather than adopting a top-down conservation approach.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

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Author contributions

Dinesh C. Nautiyal – Conceptualisation, Investigation, Methodology, Supervision; Kumar Manish – Writing original draft, review and editing, Formal analysis, Resources, Software, Validation, Visualisation

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Appendices

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Data type: pdf

Explanation note: **appendix A.** Important vegetational parameters of six forest sites. + – species present at the forest with < 10% IVI. TBA – total basal area, IVI – Importance value index. Units: density (ha^{-1}), TBA (m^2 ha^{-1}), cover (m^2 ha^{-1}). **appendix B.** The distribution of tree families and their contribution to total genera and species in six tropical semi-evergreen forest sites. Dashed entries indicate absence of respective genera/species at a sampling site.

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